

# Innovation in Enabling SSL Technology

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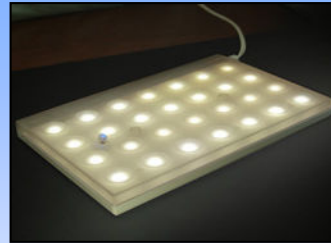
High-flux light-emitting diodes (LEDs) have shown remarkable improvements over the past decade, but they are only now being integrated into solid state lighting (SSL) systems.

This situation recalls the early days of electric lighting in the 1880s, when the development of the practical incandescent lamp presaged the development of lamp sockets, insulated wiring, switches, lamp shades and glass diffusers. Designing these lighting systems required innovation in many areas beyond that of the incandescent lamp.

Today we are repeating history. We have high-flux LEDs; we now need to enable them with SSL systems. This has required a surprising amount of innovation in electronics, optics, thermal management, and more.

# Current SSL Applications

- **White Light**
  - Under-counter lighting
  - Decorative lighting
  - Display lighting
  - Task lighting
  - Downlights
  - Step lights



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Current white light SSL applications are limited to:

- Under-counter lighting
- Decorative lighting
- Display lighting
- Task lighting
- Downlights
- Step lights

This is to be expected, as these are still the early days of SSL development. We have the high-flux LEDs, but we are still learning how best to use them in the design of SSL products.

# Future SSL Applications

- **General Illumination**

- Office lighting
- Retail lighting
- Warehouse lighting
- Roadway lighting



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Barring any unforeseen roadblocks, it is expected that SSL will eventually outperform incandescent, fluorescent, and HID luminaires in terms of luminous efficacy and cost of ownership. (This may include OLEDs for linear fluorescent lamp replacements.)

Applications will include office, retail, warehouse, and roadway lighting, leaving such niche applications as narrow-beam façade illumination and searchlights, which require point sources with extreme peak luminances.

# Specifying SSL Today

- Photometric measurements
- Color and intensity binning
- Color Rendering Index
- Thermal management
- Color temperature
- LED lifetime
- Electronics
- Optics
- Et cetera



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Specifying SSL products today is not an easy task. Lighting designers and specifiers currently have to contend with:

- Photometric measurements
  - Color and intensity binning
  - Color Rendering Index (CRI)
  - Thermal management issues
  - Color temperature
  - LED lifetime
  - Electronic drivers and DC power supplies
  - Network lighting controls
  - Luminaire optics
- and more.

# What The Engineer Sees

- **System Design**
  - Light-emitting diodes
  - Electronics design
  - Optical design
  - Thermal design
  - Photometry
  - Colorimetry
  - Controls
  - Manufacturing



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Worse, these issues are not restricted to lighting designers and specifiers. Most architectural luminaire manufacturers are also struggling with this plethora of unfamiliar topics. LEDs are not "just another light source" that can replace incandescent and compact fluorescent lamps in existing luminaire housing designs.

The luminaire designer must approach SSL from a system design point of view, wherein component may interact in unexpected and often undesirable ways. The designer must consider:

- Light-emitting diodes
  - Electrical properties
  - Thermal properties
  - Optical properties
  - LED binning
  - LED degradation
- Electronics design
  - AC-to-DC converters
  - Electronic drivers
  - Optical and thermal feedback
  - Network communications
- Optical design
  - Luminous intensity distribution
  - Color mixing
  - Actinic radiation
  - Diffractive and holographic optical elements
- Thermal design
  - LED temperature dependencies
  - Heat sink materials
  - Heat spreader materials
  - Heat pipes
  - Peltier coolers
- Photometry
  - IESNA LM-79
  - IESNA LM-80
  - Absolute versus relative photometry
- Colorimetry
  - ANSI C78:377
  - Color binning
  - Color Rendering Index
  - Spectral power distributions
  - LED chromaticity

# Specifying SSL Tomorrow

- **Applications**
- **Aesthetics**
- **Energy savings**
- **Lighting controls**
  - **Intensity**
  - **Color temperature**
  - **Scheduling**
  - **Daylight harvesting**
  - **Load shedding**

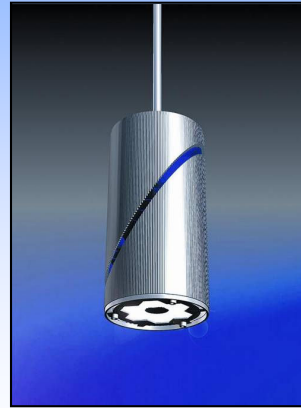


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Once however lighting manufacturers have mastered the art of manufacturing SSL luminaires, lighting designers and specifiers will feel comfortable in considering SSL products as “just another light source.” Their focus will then properly be on:

- Applications – what luminaires are best suited for a given lighting situation?
- Aesthetics – does the luminaire complement the architectural design?
- Energy savings – will the luminaire provide long-term savings that will justify its initial cost?
- Lighting controls – what lighting controls can be used to save energy and enhance the user's environment?

# What The Customer Wants

- What the customer should see ...

**“Make everything as simple as possible, but not simpler.”**

Albert Einstein



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What the customer – the person who actually lives and works under the light provided by the SSL luminaire – really wants to see is something as simple as an incandescent lamp. Walk into the room, turn on the lighting, and forget that the luminaires are even there.

## Current SSL Issues

- **Photometric measurements**
- **LED lifetime predictions**
- **Thermal management**
- **Color Rendering Index**
- **Intensity / chromaticity**
- **Color temperature**
- **Electronics design**
- **Optical design**

I. Ashdown, 2007. "Specifying Solid State Lighting,"  
*Construction Specifier* (to appear)

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... but we are not there yet. Some of the issues that luminaire manufacturers must address before SSL becomes as commonplace as fluorescent and incandescent lighting include:

- Photometric measurements
- LED lifetime predictions
- Thermal management
- Color Rendering Index
- Intensity and chromaticity control
- Color temperature
- Electronics design
- Optical design

These issues are addressed in the presentation handout, "Specifying Solid State Lighting," from the perspective of a lighting designer or specifier working with today's SSL products.

Due to lack of time, only a few of the points covered in the handout can be presented here.



# Photometric Measurements

- LEDs are temperature dependent
- Color temperature must be specified
- IESNA LM-79 recommended



I. Ashdown, 2007. "Changing White Light," *LD+A*, December 2006

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Many SSL luminaire manufacturers are currently quoting the luminous efficacy of the bare LEDs they use in their products. Unfortunately, this may grossly mislead any lighting designers or specifiers who rely on the manufacturer's data sheets.

LEDs are temperature dependent, with their luminous efficacy (the quantity of light produced per unit of electrical power consumed, measured in lumens per watt) decreasing with increasing temperature. The LED manufacturers measure the light output of their products at room temperature (25° C), but the LEDs are typically operated at temperatures ranging from 90 to 150° C. Combined with the usual light losses due to the luminaire optical system, the luminous efficacy of the luminaire can easily be less than half that of the bare LEDs stated by the luminaire manufacturer.

Until very recently, the luminous efficacy of LEDs also depended on their color temperature – warm white LEDs produced considerably less light per input watt than cool white LEDs. If an SSL luminaire manufacturer states so many lumens per watt for a product, this likely applies to cool white LEDs only.

At the very least, SSL manufacturers should have their products tested in accordance with the forthcoming IESNA LM-79 standard for SSL luminaire measurements. This will give lighting designers and specifiers the confidence they need that the product data sheets are suitable for use with engineering calculations.

## LED Lifetime Predictions

- **50,000 hours applies to LEDs only**
- **L<sub>70</sub> metric conflicts with modern lighting design practices**
- **Dependent on thermal environment**
- **Must consider luminaire MTTF**
- **Electronics probably limiting factor**



Much ado has been made about the 50,000 to 100,000 hour lifetime of LEDs, but these figures do not necessarily apply to the SSL luminaires they are mounted in.

Modern linear fluorescent lamps typically have “lamp lumen depreciation” (LLD) figures of 90% or better over their 20,000 hour lifetime. The proposed L<sub>70</sub> metric for IESNA LM-80 assumes an LLD of 70% over the estimated LED lifetime. This means that lighting designers will need to over-design their SSL installations by 40%. (One solution is for luminaires with optical feedback to maintain constant light output over their predicted lifetime.)

The actual lifetime of LEDs is very much dependent on their thermal environment. Inadvertent overheating LEDs typically results in increased lamp lumen depreciation and even catastrophic failures. SSL luminaire designers need to pay particular attention to their thermal designs.

Finally, the lifetime metric of interest to the consumer is that of the luminaire, not the LEDs. In this case it will be the electronics that will be the limiting factor in determining the mean-time-to-failure (MTTF), with electrolytic capacitors the most likely suspect in any failure.

# Thermal Management

- Proper heat dissipation essential
- Heat pipes more efficient than heat sinks

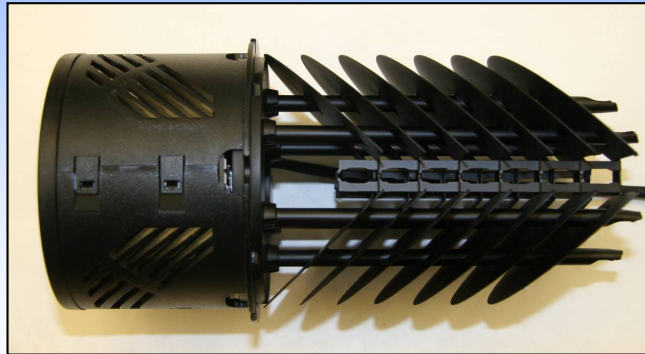


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Thermal management is probably the key issue in SSL luminaire design today. Luminaire manufacturers have little experience in maintaining luminaire housings at temperatures suitable for electronic components, and even less experience in managing conducted as opposed to radiated heat.

The current generation of recessed SSL downlights for architectural applications uses massive aluminum heat sinks, but these are clearly not a long-term solution for low-cost luminaires. A much better solution is to use heat pipes, which conduct heat much more efficiently than solid aluminum blocks.

The disadvantage of heat pipes is that they require proprietary packaging techniques to couple them to the LEDs. Until the LED manufacturers design LED packages with integral heat pipes, this will remain a barrier to entry for many smaller luminaire manufacturers.

## Color Rendering Index

- **CRI metric is not generally applicable to white light LEDs (CIE 177:2007)**
- **Typical daylight office environment has CRI of less than 80**
- **CIE Technical Committee 1.69 currently working on revised color rendering metrics**



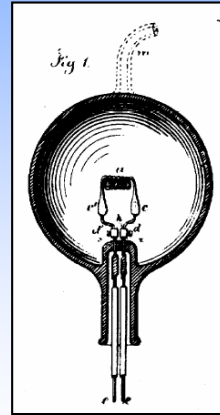
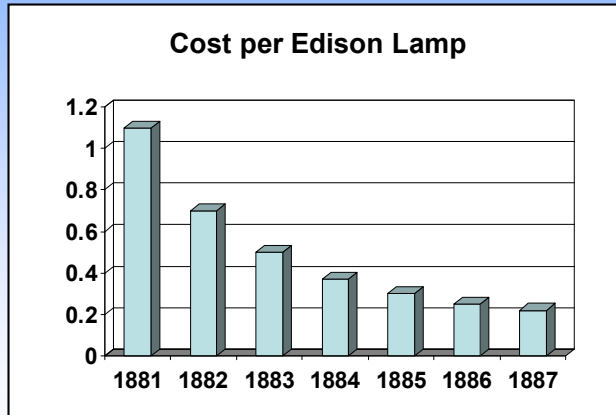
The CIE Color Rendering Index was originally developed in the 1950s to rank the color rendering properties of fluorescent lamps. While it is currently being promoted for use with SSL products, a just-released CIE technical report has concluded that the CRI metric is not generally applicable to white light LEDs.

It is also interesting to note that while some lighting designers emphasize the need for high-CRI light sources, the CRI of daylight in a modern office environment is typically less than 80, due to the blue-green color of office windows with low-E glazing.

Regardless, CIE Technical Committee 1.69 is currently investigating various proposed color rendering metrics for white light sources that will supplement and eventually replace the current CRI metric.

# The Cost of SSL

- Manufacturing costs will come down ...



Source: Silverberg, R. 1967. Light for the World. Van Nostrand.

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Finally, there are concerns that SSL products are currently too expensive in comparison with incandescent and fluorescent luminaires, even with long-term energy savings considered, and that the cost of manufacturing LEDs may not decrease enough to make SSL an economically viable technology.

With this in mind, it is instructive to consider the reduction in cost of Edison incandescent lamps from 1881 through 1887. The first commercially available lamps required some 200 hand operations to manufacture each one, with an initial cost of \$1.10 per lamp (at a time when average annual salaries were \$500). Automation quickly reduced this cost to \$0.22 per lamp.

The same cost reductions occur with any mass-produced product, from microwave ovens to cell phones. The cost of SSL products will come down.

## Current Applications (1890)

- State-of-the-art in electric lighting



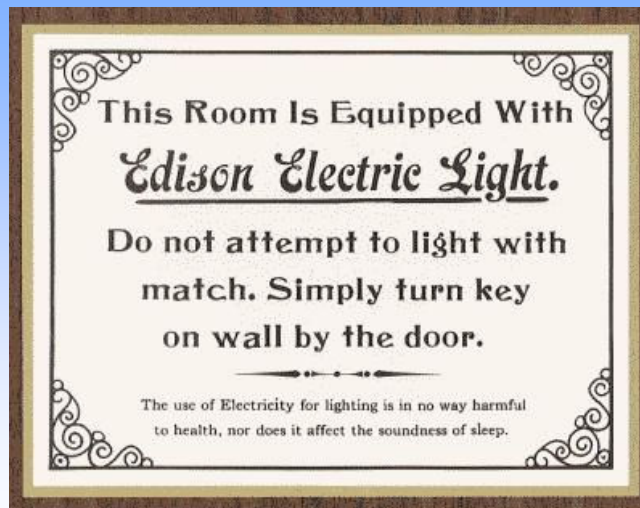
Images copyright Edisonian LLC

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These are indeed the early days of solid state lighting development. The products we are currently seeing being offered for sale are reminiscent of the first electric lighting fixtures manufactured in the 1890s.

Today's SSL products will undoubtedly seem just as quaint in ten years' time. Regardless, they are absolutely necessary for the development of the SSL industry – we learn by doing, and innovation is all part of the process.

# Thank You



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Thank you.